Test and Analysis of Low Voltage Ride-through Characteristic of Wind Farm

HU Hong-bin[1], MENG Qing-tian[1], BU He[2], REN Yong-feng[*2]

Corresponding Author: REN Yong-feng, Ph.D, Professor, engaged in wind power generation technology and power quality research.

Project supported by the Program for New Century Excellent Talents in University (NCET-11-1018); the Key Project of Chinese Ministry of Education(210037); the Ph.D. Foundation Program of Inner Mongolia Natural Science (2011BS0903) and the Talents Found Project of the Inner Mongolia.

[1]Inner Mongolia Electric Power Research Institute , Hohhot 010020 , China.

[2]Electric Power College, Inner Mongolia University of Technology , Hohhot 010051 ,China.

hhb9393@126.com; mqt2000@126.com; buhe8888@126.com; *renyongfeng@vip.sina.com

Abstract

With the increasing penetration rate of wind power in power system, the mutual influence between wind power and electric power system is more and more severe, the power system make mandatory requirements for grid-connected wind turbines can operate uninterruptedly under grid faults. In this paper, field testing characteristic of low voltage ride-through (LVRT) for directly driven permanent magnet synchronous generator (PMSG) in Inner Mongolia power grid is analyzed. Movable LVRT test device, adopted by the test program, which based on the principle of impedance differential voltage, is introduced. Test results show that the wind turbines in the wind field meet the requirements of state grid enterprise standard for LVRT ability. In the process of the voltage sag test, wind turbines can operate uninterruptedly and guarantee the power grid operate safely and stably, the stability and the security of system is thus enhanced.

Keywords

Wind turbines; LVRT; Movable LVRT Test Device; Field Testing

Introduction

At the present stage, wind power has developed rapidly in our country, and penetration rate of wind power in the grid is increasing. The interplay between wind turbines and grid is becoming more and more severe. However, most wind turbines are distributed in areas of weak power grid, which will inevitably affect the operating stability and power quality of power grid. State Grid Corporation of China has successively formulated relative enterprise standards “Q/GDW392-2009 technical regulations for wind farms connected to power grid” and “GB/T 19963-2011 technical regulations for wind farms connected to the power system”, and both request wind turbines connected to grid be capable of LVRT. Compared with conventional thermal power, wind power has two totally different characteristics: the first one is that the wind turbine output depends on the power of the wind but the power of wind is uncontrollable in the process of power generation, and the randomicity of wind speed and direction lead to the intermittence and volatility of wind power output; The second is that the wind turbine don’t respond to power imbalance in the system and it cannot through the disturbance, therefore, it has weak stability and weak disturbance rejection [1-5]. With the increasing penetration rate of wind power in the grid, the whole system will be hard to restore and possibly the system will be partly or completely beakdown if the generator still take disconnection passively when power grid at faults [6]. Thus, the new grid principles demand that when power grid faults, wind turbines connected to grid should have certain LVRT abilities and also can return to normal operation after the fault was removed. At present, massive studies concerning LVRT have been conducted home and abroad with the purpose of improving the grid’s acceptance ability for wind power and make wind power a friendly power of power system [7-13].

Authorized by a wind power co., LTD in Inner Mongolia, the electric power research institute made field test of the LVRT ability of wind turbine in the wind farm according to the State Grid Corporation enterprise standard “Q/GDW 392-2009 technical regulations for wind farms connected to the power grid” and IEC 61400-21： 2008 "Measurement and

assessment of power quality characteristics of the grid connected wind turbines". In this paper, the field test of LVRT is analysed according to the technical regulations for wind power connected to power system and combines with the wind power's effect on the power system.

Technical Regulations for Wind Farms Connected To Power System

Low voltage ride-through ability refers to that in the power grid operation, when the system disturbance or distal (near) end faults can cause local voltage sag instantaneously, power supply's ability to maintain grid-connected operation during this period.

Basic Requirements

Figure 1 show the LVRT requirement for wind power plants.

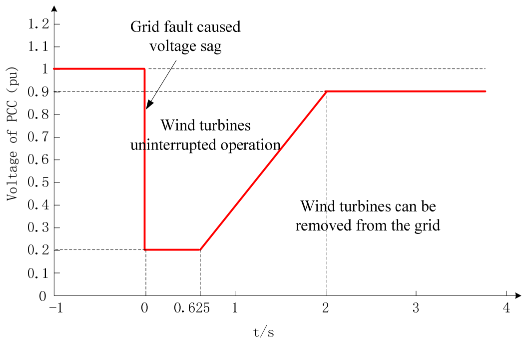

FIG.1 LVRT REQUIREMENT FOR WIND POWER PLANT

(a) When the voltage of common connected grid point (PCC) dip to 20% of the nominal voltage, wind turbines should guarantee connected to the grid and operating 625ms uninterruptedly.

(b) When the voltage of common connected grid point (PCC) return to 90% of the nominal voltage within 2s after grid fault clearance, wind turbines should guarantee connected to the grid and operating uninterruptedly.

When electric power system break down in different type of faults (three-phase short circuit fault, two phase short circuit fault, single phase grounding fault), if the examination voltage of PCC in voltage contour line and above all areas in figure 1, wind turbines must ensure connected to the grid and uninterrupted operation; Otherwise, allow cut out the wind turbines from power grid [5, 6].

Recovery of Active Power

For the wind farm not cut off from power system during grid fault, the active power should be fast recovery after the fault clearance, since the fault clearing moment, at least at power variation rate 10% return to normal value.

Dynamic Reactive Power Support Ability

For total installed capacity over million kilowatt scale wind fields, when the three-phase short circuit fault occur in power system and cause voltage sag, each wind farm should have the following dynamic reactive power support ability in the process of LVRT:

(a) When the wind farm voltage of PCC is in the range of 20% ~ 90% nominal voltage, wind farm should be able to support voltage recovery by injecting reactive current to grid; Since the moment of voltage sag, dynamic reactive current control of the response time is not more than 75ms. Duration time should be not less than 550 ms.

(b) The dynamic reactive current of wind farm injecting to power system:

$$I_T \geq 1.5\times(0.9-U_T)I_N\text{，}\quad (0.2\leq U_T\leq 0.9)$$

Where U_T are voltage standard values of PCC. I_N is wind farm rated current.

Overview of Wind Turbine LVRT

Basic Parameters of Wind Turbine

The basic information of the measured wind turbine is presented in table 1 and table 2.

TABLE 1 BASIC INFORMATION OF A02WIND TURBINE

Wind turbine types	3 blades、horizontal shaft、upwind
Hub height	70m
Leaf blade control mode	Variable pitch
Rotational speed control	Variable speed
Control system type and software version	KN-WTCS850-DD-2，V9.0.2
Blade type and serial number	27.4m，007.008.011
Blade length	27.4m
Gear box type and serial number	FL850H-WXA，F6548
Generator type and serial number	Brushless electric excitation synchronous generator
Converter type and serial number	full power converter (30080053A001180017)
Chopper type	HWCCB1500-2，0.75Ω

TABLE 2 RATING DATA OF WIND TURBINES

Rated power(kW)	850
Rated wind speed (m/s)	13.5
Rated reactive power (kVar)	400
Rated current(A)	2×365A
Nominal voltage(V)	690
Rated frequency(Hz)	57

Basic Principle of LVRT

LVRT schematic diagram is shown in figure 2.The LVRT module is used to consume electrical energy when grid voltage dips, and maintain the dc bus voltage stability, achieve wind power system LVRT functions. When the converter detected grid voltage dip, and residual voltage is within the scope of LVRT curve, the system turn into state of LVRT. According to the voltage dip depth, a certain proportion of reactive current is injected to power system to support the grid voltage, residual current is used to maintain active output. When the active power of generator is larger, in addition to the energy output to power grid during LVRT, redundant energy is absorbed by the chopper resistance to maintain conservation of energy and stable dc bus voltage. When the grid voltage recovery, the converter reduce the reactive power support, and restore grid-side active power output quickly, tracking the master controller power given, the converter return to normal and stable operation. Wind turbines is connected to the grid and uninterrupted operation is guaranteed.

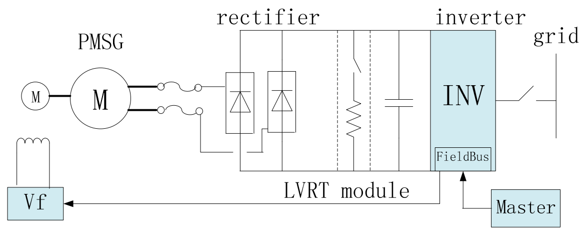

FIG.2 THE DIAGRAM OF LVRT PRINCIPLE

Test Equipment and Program

LVRT Test Equipment

The test equipment of LVRT consists of a container and a remote control room, the container is equipped with series and parallel reactor and switches, UPS and other devices. Rated voltage is 690V, rated capacity is 3MW.

The circuit structure of LVRT test equipment as shown in figure 3, the test device can produce different types (three phase short-circuit, two phase short circuit) and different depth of voltage dip, in order to meet the test requirements of LVRT. Different depth of voltage dip can be realized by changing the connection way of current limiting reactor and the short-circuit reactance.

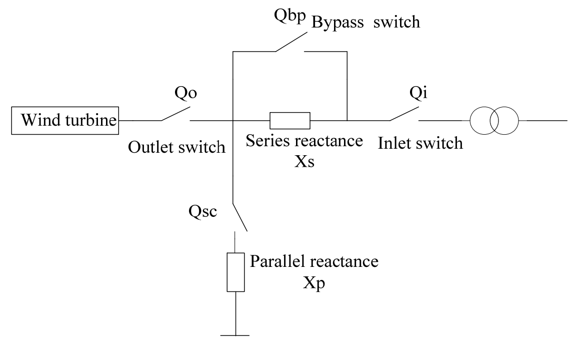

FIG.3 LVRT TEST CIRCUIT DIAGRAM

Test Program

In the process of testing LVRT functional, the software and hardware of wind turbine are not allowed to make any changes. The LVRT test project of wind turbine is as follows:

1、 Wind turbine has not put into operation (no load) : Test two phase and three-phase voltage dip case, examine the configuration for voltage dip of test equipment.

2、 Wind turbines operating in low power state（0.1Pn≤P≤0.3Pn）: Test two phase and three-phase voltage dip case.

3、 Wind turbines operating in high power state（P≥0.9Pn）: Test two phase and three-phase voltage dip case.

The LVRT test points voltage of wind turbine dip amplitude and duration time are shown in table 3.

TABLE 3 TEST CONTENT

Operation condition	Voltage dip amplitude（p.u.）	Duration(ms)
0.1Pn≤P≤0.3Pn	0.75±0.05	1705±20
	0.50±0.05	1214±20
	0.20±0.05	625±20
P≥0.9Pn	0.75±0.05	1705±20
	0.50±0.05	1214±20
	0.20±0.05	625±20

Test Data and Analysis

This paper only analyzes test datas of high power output, two kinds of voltage sag(two phrase, three

phrase) and two kinds of voltage sag situation(50%Un, 20%Un), and make comprehensive analysis on the GHFD56-850/II-2 type wind turbine's LVRT characteristics.

The following waveform diagram are labelled with per-unit value, and the fiducial value are : the machine terminal line voltage $U_n = 690V$, generator current $I_n = 710A$ and rated power $P = 850kW$.

Voltage Dip to 50%Un（P≥0.9Pn）

1) Three-Phase Voltage Symmetrical Sag

Figure 4、5、6 are respectively voltage, current, active and reactive power waveform when grid voltage three phrase symmetrical dip to 50% Un.

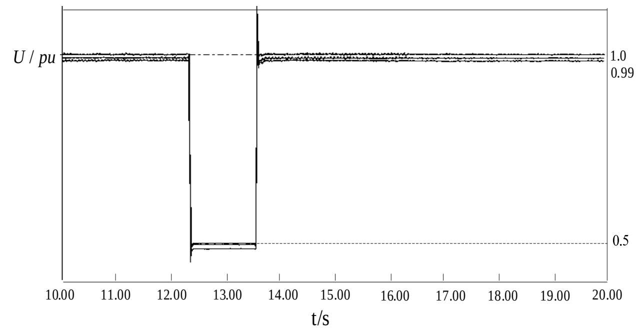

FIG.4 GRID LINE VOLTAGE（HIGH POWER、50%Un）

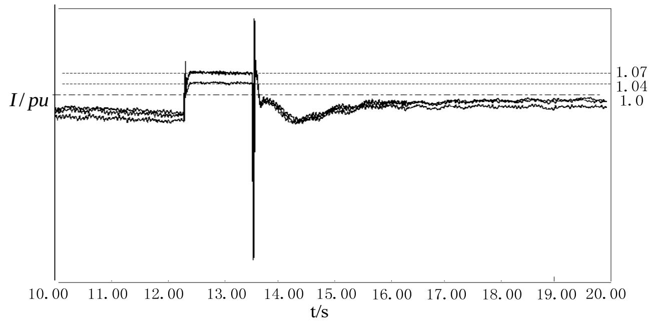

FIG.5 CURRENT CURVE（HIGH POWER、50%Un）

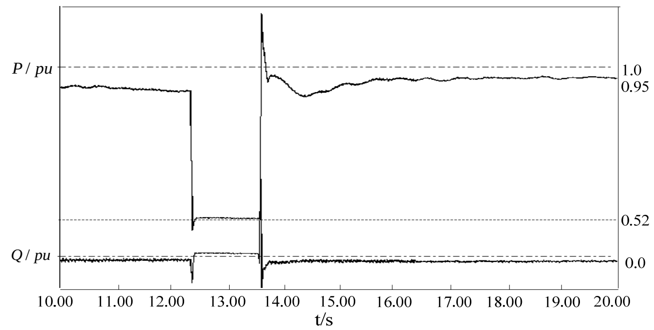

FIG.6 ACTIVE/REACTIVE POWER (HIGH POWER、50%Un）

From figure 4, we can see before the voltage sag, the amplitude of wind turbine line voltage is 0.99pu; it dip to 0.50pu during the sag period; the time of duration is 1214ms.In figure 5, before the voltage sag, the amplitude of generator current is 0.93pu; during the sag period, A phrase and B phrase current are both 1.07pu, and C phrase current is 1.04pu, which all within the current limit of the converter; After voltage recovered, the current recovered to the amplitude before voltage sag. In figure 6, before voltage sag, the wind turbines' active power P is 0.92pu, reactive power Q is 0; During the sag period, active power P dip to 0.52 pu, reactive power Q up to 0.01pu; After voltage recorved, active power recovered to an amplitude of 0.95pu, reactive power recovered to 0.

2) Two Phase Voltage Sag

Figure 7, 8, 9 show the voltage, current, active and reactive power waveform respectively when two-phase grid voltage dip to 50% nominal value.

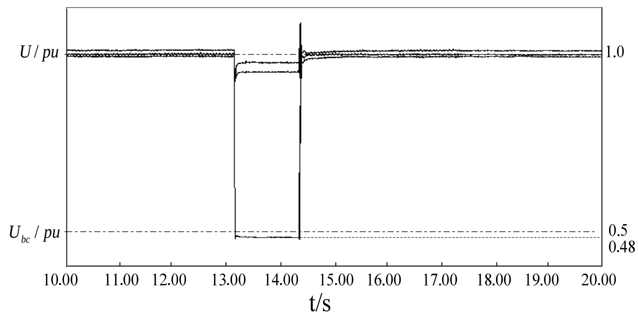

FIG.7 GRID LINE VOLTAGE（HIGH POWER、50%Un）

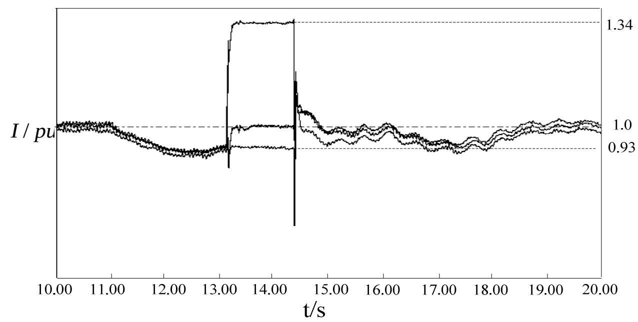

FIG.8 CURRENT CURVE（HIGH POWER、50%Un）

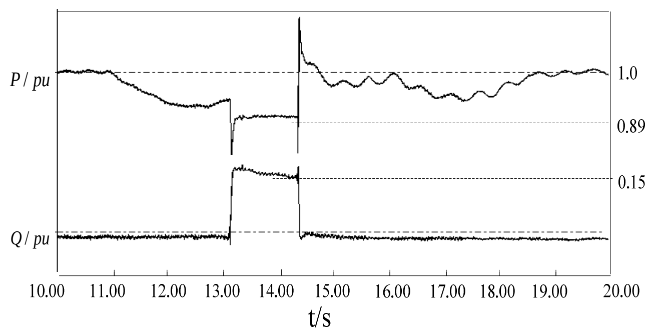

FIG.9 ACTIVE/REACTIVE POWER (HIGH POWER、50%Un)

Figure 7 shows that wind turbine line voltage u_{bc} amplitude is 1.0pu before voltage sags, during

voltsge sags it reduce to 0.48pu; Duration of voltage sags for 1214 ms. Figure 8 shows that current amplitude is 0.93pu before voltage sags; During sags the C-phase current is 1.34pu, A-phase current is 1.0pu, B-phase current is 0.93pu, three phase current are within the limit value of converter. After voltage recovery, current amplitude return to normal. Shown in figure 9, before voltage sags, wind power generator active power P amplitude is 0.93pu, reactive power Q amplitude is zero; During the voltage sags, active power P amplitude dip to 0.89pu, reactive power Q increased to 0.15pu; After voltage recovery, active power return to 1.02pu, reactive power return to zero.

Voltage Dip to 20%Un（P≥0.9Pn）

1) ***Three-Phase Voltage Symmetrical Sag***

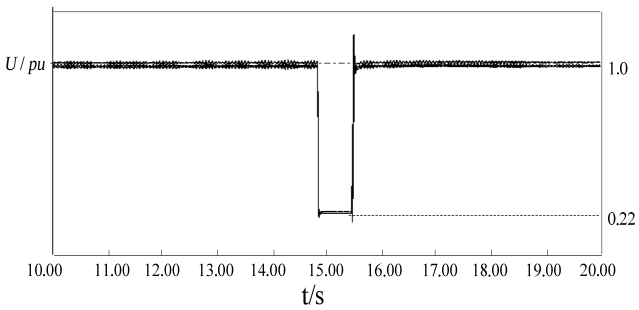

FIG.10 GRID LINE VOLTAGE（HIGH POWER、20%Un）

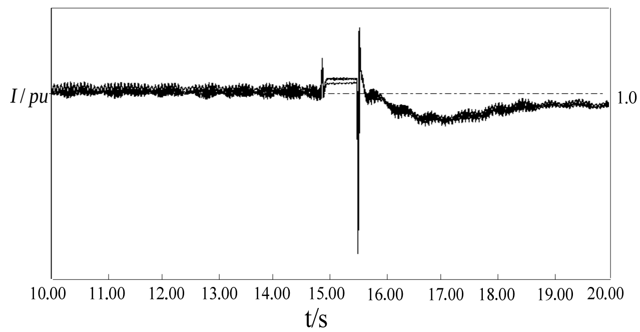

FIG.11 CURRENT CURVE（HIGH POWER、20%Un）

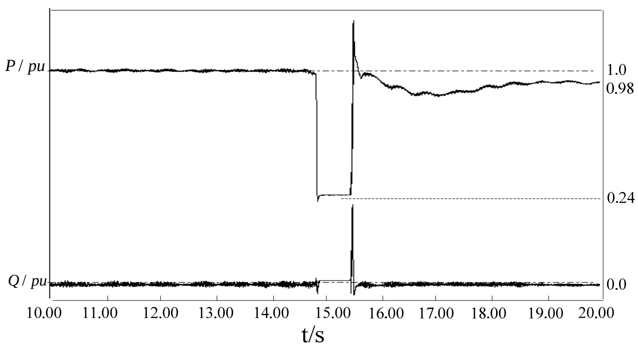

FIG.12 ACTIVE/REACTIVE POWER (HIGH POWER、20%Un)

Figure 10、11、12 are respectively the voltage, current, active and reactive power waveform when grid voltage three phrase symmetrical dip to 20%Un.

Seeing from figure 10, when the voltage sag changes from 50% to 80%，the duration is 625ms.During the period, the current increase a little. In figure 12, before the voltage sag，the wind turbines' active power P amplitude is 1.0pu，reactive power Q amplitude is 0；During the voltage sag period, the active power P amplitude dip to 0.24 pu，reactive power Q amplitude up to 0.01pu；After the voltage recorved, active power recovered to 0.98pu，reactive power Q amplitude is 0，and operating in unit power factor.

2) ***Two Phrase Voltage Sag***

Figure 13、14、15 are respectively the voltage, current, active and reactive power waveform when grid voltage two phrase dip to 20%Un.

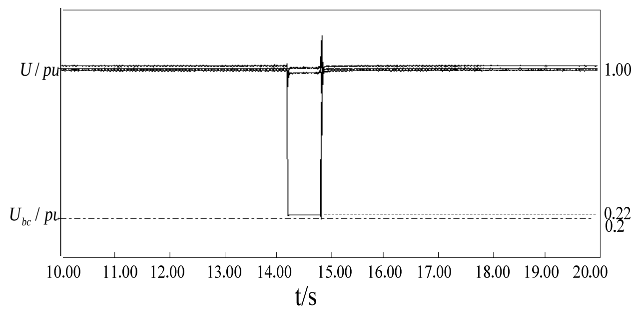

FIG.13 GRID LINE VOLTAGE（HIGH POWER、20%Un）

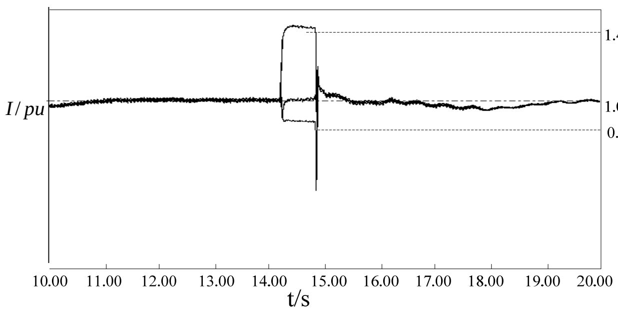

FIG.14 CURRENT CURVE（HIGH POWER、20%Un）

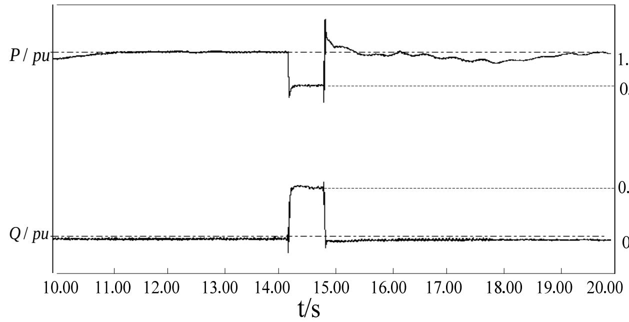

FIG.15 ACTIVE/REACTIVE POWER (HIGH POWER、20%Un)

When two phrase voltage dip to 20%Un，the duration time is 625ms.In figure 14, before the

voltage sag, the wind turbines' current amplitude is 1.0pu; during the sag period, A、B、C phrase current are respectively 1.0pu , 0.87pu , 1.45pu,which all within the current limit of the converter. Active power P amplitude is 0.82pu, reactive power Q amplitude is 0.27 pu. After the voltage recovered, the current recovered to the amplitude before the sag, and the active power recovered to 1.03pu, reactive power amplitude is 0.

Conclusions

Through field testing of LVRT for the wind turbine in the wind farm. Under two kinds of working conditions: high power and low power, two phrase and three phrase short circuit were tested when the voltage dip to 50%Un and 20%Un respectively. During the process of test, the wind turbine did not cut off from the grid and operating uninterruptedly. A02 wind turbine in this wind farm meet the LVRT requirement in the "tecnical regulations for wind farm connected to power grid" which was formulated by the State Grid Corporation Enterprise Standards Q/GDW392-2009.

REFERENCES

Alepuz, Salvador; Calle, Alejandro; Busquets-Monge, Sergio. Use of Stored Energy in PMSG Rotor Inertia for Low-Voltage Ride-Through in Back-to-Back NPC Converter-Based Wind Power Systems[J]. IEEE Transactions on Industrial Electronics,2013,60(5): 1787-1796.

Aung Ko, Thet; Hiroumi, Saitoh. Pitch Control Based on Voltage Dip Detection for Improving The LVRT of Wind Farm[J]. IEEJ Transactions on Electrical and Electronic Engineering,2012,7(2):136-143.

Caixia Wang,James D. McCalley. Impact of Wind Power on Control Performance Standards[J]. Electrical Power and Energy Systems, 2013(47): 225-234.

Dennis Y.C. Leung, Yuan Yang. Wind Energy Development and its Environmental Impact: A Review[J]. Renewable and Sustainable Energy Reviews, 2012(16):1031-1039.

Hua Geng, Cong Liu, Geng Yang. LVRT Capability of DFIG-Based WECS Under Asymmetrical Grid Fault Condition[J]. IEEE Transactions on Industrial Electronics, 2013,60(6): 2495-2509.

John Kabouris,F. D. Kanellos. Impacts of Large-Scale Wind Penetration on Designing and Operation of Electric Power Systems[J]. IEEE Transactions on Sustainable Energy,2010,1(2):107-114.

Liying ZHANG, Tinglu YE, Yaozhong XIN. Problems and Measures of Power Grid Accommodating Large Scale Wind Power [J]. Proceedings of the CSEE, 2010,30 (25): 1-9.

M., Molinas;J.A., Suul; T., Undeland. Low Voltage Ride Through of Wind Farms With Cage Generators: STATCOM Versus SVC[J]. IEEE Transactions on Power Electronics,2008,23(3):1104-1117.

S. M. Muyeen, Rion Takahashi, Toshiaki Murata. A Variable Speed Wind Turbine Control Strategy to Meet Wind Farm Grid Code Requirements[J]. IEEE Transactions on Power Systems, 2010,25(1):331-340.

Teng Long, Shiyi Shao, Member, Paul Malliband. Crowbarless Fault Ride-Through of the Brushless Doubly Fed Induction Generator in a Wind TurbineUnder Symmetrical Voltage Dips[J]. IEEE Transactions on Industrial Electronics,2013,60(7): 2833-2841.

Xiaoming YUAN, Shijie CHENG, Jinyu WEN. Prospects Analysis of Energy Storage Application in Grid Integration of Large-scale Wind Power [J]. Automation of Electric Power Systems, 2013, 37 (1): 14-18.

Xing ZHANG, Long-yun ZHANG, Shu-ying YANG. Low Voltage Ride-through Technologies in Wind Turbine Generation [J]. Proceedings of the Chinese Society of Universities for Electric Power System and its Automation,2008,20 (2) :1-8.

Zilong ZHAO, Weining WU, Wei WANG. A Low Voltage Ride Through Technology for Direct-drive Wind Turbines Under Unbalanced Voltage Dips [J]. Automation of Electric Power Systems,2009,33(21): 87-91.